

CLAIMS

1. A method of acousto-optical imaging of an object
5 to be imaged (OBJ) comprising the steps consisting in:

(a) generating an incident optical wave (INC), of frequency f_I , and a reference optical wave (REF), of frequency f_R , this reference wave being coherent with the incident wave (INC), and exhibiting therewith a
10 known phase difference $\phi_i(t)$,

(b) vibrating in a first object direction (x_0) and at an acoustic frequency f_A , a zone (Dx, Dy, Dz) of the object to be imaged (OBJ) with the aid of a vibration generating device (TRANS),

15 (c) applying said incident wave (INC) to the object to be imaged (OBJ), and thus generating a scattered signal wave (DIF),

(d) applying at least a part of the scattered signal wave to a detection device (DET),

20 (e) applying the reference wave (REF) to the detection device (DET) without making it pass through the object to be imaged (OBJ), thereby generating at the point \underline{r} of the detection device (DET) an interferogram $I(\underline{r}, t)$ varying over time t ,

25 (f) extracting a digital information item from the interferogram $I(\underline{r}, t)$, and

(g) obtaining the coordinates (U, V, W) of a point of measurement of the object to be imaged (OBJ), to which the digital information item relates.

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2. The method of acousto-optical imaging as claimed in claim 1, in which in the course of step (f), an acoustic component of the part of the scattered signal wave applied to the detection device (DET) is detected,
35 this acoustic component being at a frequency corresponding to the sum of the frequency f_I of the incident wave (INC) and of a harmonic of the acoustic frequency f_A .

3. The method of acousto-optical imaging as claimed in claim 2, in which, in the course of step (a), said reference wave (REF) is generated at a frequency f_R equal or substantially equal to the sum of the frequency f_I of the incident wave (INC) and of said harmonic of the acoustic frequency f_A .

4. The method of acousto-optical imaging as claimed in claim 3, in which in the course of step (b), an acoustic wave is generated, focused at a focal point situated in the object to be imaged (OBJ), and in which, in the course of step (g), the coordinates (U, V, W) of the measurement point are obtained as being the coordinates of said focal point.

5. The method of acousto-optical imaging as claimed in claim 4, in which steps (a) to (g) are repeated for various focal points of the acoustic wave in the object to be imaged (OBJ), these various focal points being aligned along the first object direction (x_0).

6. The method of acousto-optical imaging as claimed in any one of claims 1 to 3, in which, in the course of a first iteration, steps (a) to (f) are performed for a first frequency f_A of the acoustic wave and a first frequency f_R of the reference wave (REF), in the course of at least a second iteration, steps (a) to (f) are repeated for a second frequency f'_A of the acoustic wave and a second frequency f'_R of the reference wave (REF), these second frequencies being coded respectively with the first frequencies, the method furthermore comprising a step in the course of which:

(f') at least one digital information item is obtained by decoding said digital information items obtained in the course of steps (f) of each iteration as a function of the frequencies used,

and in which, in the course of step (g), the coordinates (U, V, W) of at least one point of measurement of the object to be imaged (OBJ) to which the digital information item obtained in the course of step (f') relates are obtained, by decoding the said digital information items obtained in the course of steps (f) of each iteration as a function of the frequencies used.

7. The method as claimed in claim 6, in which the sequence of following operations is performed:

- a scan is performed of the frequency of the acoustic wave, which is focused on an interval of points with coordinates $([U-Dx, U+Dx], V, W)$ extending around the point with coordinates (U, V, W) along the first object direction (x_0),

- a scan is performed jointly of the frequency f_R of the reference wave (REF) in such a way as to keep f_R substantially equal or equal to $f_I \pm H.f_A$, H being a nonzero integer,

- an interferogram $I(f_A, V, W, \underline{r})$ associated with the set of points $([U-Dx, U+Dx], V, W)$ of the extended interval is recorded for each pixel \underline{r} and for each frequency f_A ;

- a 1D frequency \rightarrow time Fourier transformation is performed, for each pixel \underline{r} , according to the frequency f_A of the interferogram $I(f_A, V, W, \underline{r})$, and

- at least one interferogram $I(\underline{r})$ associated at least with a measurement point with coordinates (U', V, W) is obtained by replacing the time obtained after the Fourier transform with the magnitude U' along the first object direction (x_0) with the aid of the speed of propagation of the acoustic wave in the object to be imaged.

8. The method of acousto-optical imaging as claimed in any one of the preceding claims, in which at least

steps (a) to (g) are repeated after having imposed a displacement of the vibration generating device relative to the object to be imaged (OBJ) along a direction not parallel to the first object direction
5 (x_0) of the object to be imaged (OBJ).

9. The method of acousto-optical imaging as claimed in any one of the preceding claims in which in the course of step (f), the complex amplitude $E_s(\underline{r})$ of the
10 acoustic component is estimated on the basis of the interferogram $I(\underline{r}, t)$.

10. The method of acousto-optical imaging as claimed in claim 9, in which the detection device (DET) used is
15 a monopixel detector, and in which, in the course of step (f), the digital information item is obtained as being the intensity of the field of complex amplitude $E_s(\underline{r})$ scattered by the object.

20 11. The method of acousto-optical imaging as claimed in claim 9, in which the detection device used is a multipixel detector, and in which in the course of step (f), the digital information is extracted as being the sum over at least a part of the pixels \underline{r} of the
25 detection device of the intensity of the complex amplitude field $E_s(\underline{r})$ scattered by the object.

12. The method of acousto-optical imaging as claimed in claim 9, in which, in the course of step (d) a
30 spatial filtering device (COL) is used, in such a way as to limit, along at least one direction, the angular extent of the part of the scattered signal wave (DIF) which is seen by each pixel of the detection device.

35 13. The method of acousto-optical imaging as claimed in claim 12, in which a spatial filtering device (COL) comprising a diaphragm, of dimensions X along a first

diaphragm direction and Y along a third diaphragm direction, and a lens of focal length L with object focus situated directly downstream of the object to be imaged (OBJ) is used so as to limit the angular extent
5 of the part of the scattered signal wave (DIF) which is seen by each pixel of the detection device, and in which the reference wave (REF) applied to the detection device (DET) is globally a plane wave.

10 14. The method of acousto-optical imaging as claimed in claim 12, in which is used a spatial filtering device (COL) comprising a diaphragm of dimensions X along the first diaphragm direction and Y along the third diaphragm direction, disposed between the object
15 to be imaged (OBJ) and the detection device (DET) at a distance L from the latter, so as to limit the angular extent of the part of the scattered signal wave which is seen by each pixel of the detection device, and in which the reference wave (REF) applied to the detection
20 device (DET) is a spherical wave emanating from a source point situated in the plane of the diaphragm.

15. The method of acousto-optical imaging as claimed in any one of claims 12 to 14, in which the reference
25 wave (REF) and the scattered signal wave (DIF) interfere on the detection device (DET) while forming a nonzero angle θ_y , θ_y being measured in the plane of incidence of these two waves on the detection device.

30 16. The method of acousto-optical imaging as claimed in any one of claims 12 to 15, in which the detection device used is a multipixel detector, and in which the part of the acoustic component, of complex amplitude $E_s(\underline{r})$, which varies rapidly in space in the plane of the
35 detection device is isolated.

17. The method of acousto-optical imaging as claimed

in any one of claims 12 to 16, in which the detection device (DET) comprises pixels disposed as a matrix comprising rows along a first detector direction (xD) and columns along a third detector direction (yD), and

5 in which step (f) comprises the following steps:

(f1) for at least one row (l) or column (c) a 1D-Fourier transform is done along this row (l) or column (c) of the detection device (DET) to the space of wave vectors, of the complex amplitude of the field $E_s(\underline{r})$, and a field $TF_1 E_s(\underline{k})$, is thus obtained for this row or column,

(f2) several zones of summation are defined in the space of wave vectors,

(f3) the intensities of the field $TF_1 E_s(\underline{k})$ at each point \underline{k} of at least one zone are summed in this zone, and

(f4) the digital information item is extracted as being a linear combination of the sums thus obtained at each zone.

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18. The method of acousto-optical imaging as claimed in any one of claims 12 to 16, in which the detection device (DET) comprises pixels disposed in a matrix comprising rows along a first detector direction (xD) and columns along a third detector direction (yD), and

25 in which step (f) comprises the following steps:

(f1) a 2D-Fourier transform is done of the complex amplitude $E_s(\underline{r})$, from the plane of the detection device (DET) to the space of wave vectors, and a field $TF_2 E_s(\underline{k})$, is thus obtained,

(f2) several zones of summation are defined in the space of wave vectors,

(f3) the intensities of the field $TF_2 E_s(\underline{k})$ at each point \underline{k} of at least one zone are summed in this zone, and

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(f4) the digital information item is extracted as being a linear combination of the sums thus obtained at

each zone.

19. The method of acousto-optical imaging as claimed in any one of claims 15 to 18, in which the angle θ_y is about equal to $3Y/2L$, in which, in the course of step (f2) are defined a first zone of summation, the so-called central zone, a second zone of summation, the so-called left zone, and a third zone of summation the so-called right zone, and in which, in the course of step (f4), the digital information item is extracted as being a linear combination of the value of the sum of the left zone and of the sum of the right zone.

20. The method of acousto-optical imaging as claimed in any one of claims 1 to 11, in which in the course of step (a),

- a laser source of wavelength λ emits an emission wave (EMI), of frequency f_L ,

- amplitude modulation means (MA) of the emission wave (EMI), generate a carrier wave (POR) of incident frequency f_I , and at least one amplitude modulation lateral band (LATMOD), which corresponds to a wave of frequency f_R ,

- a semireflecting mirror, transmits a part of the lateral band wave (LATMOD) and a part of the carrier wave (POR) forming the incident wave (INC), and reflects a part of the carrier wave (POR) and a part of the lateral band wave (LATMOD) forming the reference wave (REF).

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21. The method of acousto-optical imaging as claimed in any one of claims 1 to 19, in which in the course of step (a),

- a laser source of wavelength λ emits an emission wave (EMI), of frequency f_L ,

- a first acousto-optical modulator (MAO1) transmits a part of the emission wave (EMI) to form the

incident wave (INC) on the object to be imaged (OBJ), and moreover generates a first frequency shifted wave (DEC), the frequency of which is shifted by a value δf_1 , possibly negative, with respect to the emission wave, and

5 - a second acousto-optical modulator (MAO2) intercepts the first frequency shifted wave (DEC) and generates a second frequency shifted wave, the frequency of which is shifted by a value δf_2 , possibly
10 negative, with respect to the shifted wave (DEC), the second frequency shifted wave forming the reference wave (REF), the frequency of which is thus shifted in frequency with respect to the incident wave (INC) by a value $\delta f = \delta f_1 + \delta f_2$, thus determining a known phase
15 difference $\phi_i(t)$ between these two waves.

22. The method of acousto-optical imaging as claimed in any one of claims 1 to 19, in which, in the course of step (a), two independent laser sources, locked in
20 phase by electronic slaving, generate the incident (INC) and reference (REF) waves, exhibiting a known phase difference $\phi_i(t)$ between them.

23. The method of acousto-optical imaging as claimed
25 in any one of claims 1 to 19, in which in the course of step (a),

 - a laser source of wavelength λ emits an emission wave (EMI), of frequency f_L ,

 - a semireflecting mirror transmits a part of the
30 emission wave (EMI) to form the incident wave (INC) on the object to be imaged (OBJ), and transmits a second part of the emission wave (EMI),

 - a first acousto-optical modulator (MAO1) intercepts the second part of the emission wave and
35 generates a first frequency shifted wave (DEC), with frequency shifted by a value δf_1 , possibly negative, with respect to the emission wave, and

- a second acousto-optical modulator (MAO2) intercepts the first frequency shifted wave (DEC) and generates a second frequency shifted wave, the frequency of which is shifted by a value δf_2 , possibly negative, with respect to the shifted wave (DEC), the second frequency shifted wave forming the reference wave (REF), the frequency of which is thus shifted in frequency with respect to the incident wave (INC) by a value $\delta f = \delta f_1 + \delta f_2$, thus determining a known phase difference $\phi_i(t)$ between these two waves.

24. The method of acousto-optical imaging as claimed in any one of the preceding claims in which the object to be imaged (OBJ) is a biological tissue.

25. The method of acousto-optical imaging as claimed in any one of the preceding claims in which the vibration generating device (TRANS) is used to obtain an acoustic cue of the zone (Dx, Dy, Dz) of the object to be imaged (OBJ), and in which the digital information item extracted in step (f) is used jointly with said acoustic cue.

26. An installation for acousto-optical imaging of an object to be imaged (OBJ) comprising:

- means for generating an incident optical wave (INC), of frequency f_i , and a reference optical wave (REF) of frequency f_r , this reference wave being coherent with the incident wave (INC) and exhibiting therewith a known phase difference $\phi_i(t)$,

- a vibration generating device for vibrating in a first object direction (x_0) and at an acoustic frequency f_a a zone (Dx, Dy, Dz) of the object to be imaged (OBJ),

- means for applying the said incident wave (INC) to the object to be imaged (OBJ), thus generating a scattered signal wave (DIF),

- a detection device (DET),
 - means for applying at least part (SIG) of this scattered signal wave (DIF) to the detection device (DET),
- 5 - means for applying the reference wave (REF) to the detection device (DET) without making it pass through the object to be imaged (OBJ), thereby generating at point \underline{r} of the detection device (DET) an interferogram $I(\underline{r}, t)$ varying over time t , and
- 10 - means (CALC) for extracting a digital information item and the coordinates (U, V, W) of a point of measurement of the object to be imaged, to which the digital information item relates, from the interferogram.
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27. The installation for acousto-optical imaging as claimed in claim 26 furthermore comprising the following elements:
- means for visualizing said digital information
- 20 item relating to said point of measurement of the object to be imaged, and
- means for displacing the object to be imaged (OBJ).
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28. The installation for acousto-optical imaging as claimed in claim 26 or 27, furthermore comprising a spatial filtering device situated downstream of the object to be imaged.